TITLE: EFFECTS OF COMBUSTION INDUCED VORTEX BREAKDOWN ON FLASHBACK LIMITS OF SYNGAS FUELED TURBINE COMBUSTORS

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1. ABSTRACT

Program Introduction: Rationale and Objective

Turbine combustors of advanced power systems have goals to achieve very low pollutants emissions, fuel variability, and fuel flexibility. Future generation gas turbine combustors should tolerate fuel compositions ranging from natural gas to a broad range of syngas without sacrificing operational advantages and low emission characteristics. Additionally, current designs of advanced turbine combustors use various degrees of swirl and lean premixing for stabilizing flames and controlling high temperature NO_x formation zones. However, issues of fuel variability and NO_x control through premixing also bring a number of concerns, especially combustor flashback and flame blowout.

Flashback is a combustion condition at which the flame propagates upstream against the gas stream into the burner tube. Flashback is a critical issue for premixed combustor designs, because it not only causes serious hardware damages but also increases pollutant emissions. In swirl stabilized lean premixed turbine combustors onset of flashback [5-6] may occur due to (i) boundary layer flame propagation (critical velocity gradient), (ii) turbulent flame propagation in core flow, (iii) combustion instabilities, and (iv) upstream flame propagation induced by combustion induced vortex breakdown (CIVB).

Flashback due to first two foregoing mechanisms is a topic of classical interest and has been studied extensively. Generally, analytical theories and experimental determinations of laminar and turbulent burning velocities model these mechanisms with sufficient precision for design usages. However, the swirling flow complicates the flashback processes in premixed combustions and the first two mechanisms inadequately describe the flashback propensity of most practical combustor designs

The presence of hydrogen in syngas significantly increases the potential for flashback. Due to high laminar burning velocity and low lean flammability limit, hydrogen tends to shift the combustor operating conditions towards flashback regime. Even a small amount of hydrogen in a fuel blend triggers the onset of flashback by altering the kinetics and thermophysical characteristics of the mixture. Additionally, the presence of hydrogen in the fuel mixture modifies the response of the flame to the global effects of stretch and preferential diffusion. Despite its immense importance in fuel flexible combustor design, little is known about the magnitude of fuel effects on CIVB induced flashback mechanism. Hence, this project will investigate the effects of syngas compositions on flashback resulting from combustion induced vortex breakdown. The project will use controlled experiments and parametric modeling to understand the velocity field and flame interaction leading to CIVB driven flashback. The outcomes of the project will allow determining design margins against flashback under CIVB.

Accomplishments Achieved During the Current Period of Performance

The project initiation date is April 1, 2008. An existing burner facility is currently being configured and modified to setup flashback experiments for the proposed work.

Plans for the Remaining Period of Performance

High Speed, PLIF and PIV imaging systems will be integrated with the burner system and tested for the proposed experimental configurations. Initial validation experimentation will be also conducted for the qualification of the apparatus. Validation experiments will include PIV imaging of non-reacting flow-field, flashback and PIV/PLIF imaging of 80%CH_4 + 20% H_2 fuel flames. The measured data will be benchmarked against data already available in the literature.

A design of experiments will be generated to systematically investigate the effects of syngas compositions [%H_2, %CO, %CH_4 and %CO_2] on the flashback propensity of the combustor. The flashback conditions in terms of burner configurations [swirl number and swirler geometries: hubless swirler and swirler with center body], mass-flow rate, equivalence ratio, pre-heat temperature, and combustor pressure will be mapped. The mapped flashback operating parameters will be classified according to their underlying flashback mechanisms. Mean and turbulent flow quantities [mean velocity, circumferential velocity and velocity fluctuations] will be measured for both non-reacting conditions. Phase locked measurements using externally forced flow and PIV will be used to investigate large coherent structures [Precessing Vortex Core (PVC) and Vortices shedding in the combustor plane] and their interactions with CIVB process.

Based on the flow-field data and flashback regime mapping parametric model will be developed to generalize the measured data. The parametric model will describe the interactions of various parameters i.e. fuel compositions, burner configurations, and operating conditions leading to CIVB flashback. Passive control of CIVB flashback through modifications burner aerodynamic using diverging nozzle and elliptic nozzles will be explored. Both diverging and elliptic nozzle allow controlling the spatial and temporal behavior of precessing vortex core (PVC) and corner vortices. Flow measurements of non-reacting conditions will be used to understand the advantages of the passive control techniques.

2. LIST OF PUBLISHED JOURNAL ARTICLES, COMPLETED PRESENTATIONS AND STUDENTS RECEIVING SUPPORT FROM THE GRANT

Students Supported Under this Grant

- Jonathon Valenzuela, undergraduate student in the Department of Mechanical Engineering
- Gilberto Corena, undergraduate student in the Department of Mechanical Engineering
- Bidhan Dam, graduate student in the Department of Mechanical Engineering
- Vishwanath Ardha, graduate student in the Department of Mechanical Engineering